## The Changing Arctic Ocean Presentation order:

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### ADDITIONAL PRESENTATIONS

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"... sum of biological interactions driving the movement of carbon from the atmosphere into the deep sea .."
OBE in the Arctic Ocean

Torres-Valdes et al. (2013)

Henson et al. (2011)

Le Moigne et al. (2015)

Daniels et al. (in prep)
OBE Key Skills

**Phytoplankton & Nutrient cycling**
- Basin-scale cycles (e.g., Torres-Valdes et al., 2013)
- Silicification (e.g., Poulton et al., 2006)
- Calcification and OA (e.g., Poulton et al., 2013, 2014)
- Photo-heterotrophy (e.g., Evans et al., 2015)
- Mixotrophy (e.g., Zubkov & Tarran 2008)

**Zooplankton**
- Metabolomics and OA (e.g., Mayor et al. 2015)
- Ecophysiology (e.g., Mayor et al., 2009, 2011a, 2014)
- Pulse-Chase (e.g., Mayor et al., 2011b, 2012)

**Carbon flux**
- OM Provenance (e.g., Mayor et al., 2011b, 2013)
- 234Th fluxes (e.g., Le Moigne et al., 2015)
- Particle flux (e.g., Riley et al., 2012)
- Global BCP (e.g., Henson et al., 2011, 2012, 2015)
- Mesopelagic C-budget (e.g., Giering et al., 2014)
- Fate of C reaching sediments (e.g., Ruhl et al., 2008)
QU: Is the Arctic Ocean BCP inefficient? Why? Where does all the PP go?

QU: How will the changing sea-ice habitat impact on phytoplankton and zooplankton trophic interactions and the fate of Arctic PP?
PHOTOPHYSIOLOGICAL PROPERTIES OF ARCTIC MARINE PHYTOPLANKTON
RELEVANCE OF SUBSURFACE CHLOROPHYLL MAXIMA AND UNDER ICE BLOOMS TO OCEAN PRODUCTIVITY

Ardyna et al. 2013 (Biogeosciences)

The Changing Arctic Ocean

Finlo Cottier  Scottish Association for Marine Science
The Arctic University of Norway, Tromsø, Dept. of Arctic and Marine Biology

“... how changes in the physical environment (ice and ocean) will affect the large scale ecosystem structure and biogeochemical functioning ...”

Related Projects
- Marine Night Program – functioning of Arctic ecosystems in the polar night.
- ARCTOS MIZ Ecosystems Program
- Joint UK-Norwegian-Korean research cruises
- Coordination with Norwegian Centre of Excellence in Autonomous Marine Operations (AMOS)

Research Partnerships
- Norwegian Arctic marine ecosystem research network
- Canadian Network of Excellence
- Greenlandic-Danish-Canadian Arctic research collaboration

Coordination with Norwegian Centre of Excellence in Autonomous Marine Operations (AMOS)
“Hot Spots” – 1° & 2° Productivity in a New Arctic?

1. Arctic Mixing Environment
2. Changing Ice Cover
3. Enhanced Wind Forcing
4. Upwelling at Shelf Edge

Rippeth et al (2015) ... Arctic sea ice decline [will] likely to lead to an expansion of mixing hotspots in the future Arctic Ocean.

Falk-Petersen et al. (2015) High productivity fuelled by winter upwelling along an Arctic shelf.

Bhatt et al (2014)

Lind & Ingvaldsen (2012)
Physics, ice, light, migration, predation, carbon

Ripfjorden – seasonally ice-covered
Kongsfjorden – permanently ice-free

MOORED INSTRUMENTS IN CONTRASTING ENVIRONMENTS

Wallace et al. 2010. L&O, 55: 831-845. Ice impacts (D)VM.


Andrew Brierley asb4@st-andrews.ac.uk
As ice thickness decreases, underwater illumination increases, effecting photosynthesis and predation: food-web impacts. 


Reduced sea ice + upwelling => conditions similar to European whaling era (1690 - 1790). This combination of physical features => high 1° and 2° prodn (diatoms + Calanus spp.), which sustained large stocks of bowhead whales.


The Arctic is not uniform: inflow cf. outflow shelves; broad cf. narrow shelves. Will impacts be uniform? COLTRANE model: N. Banas.

Bluhm et al. 2015. Prog. Oceanog.

Seals provide CTD data, light field, and predator movements: L. Boehme

Isachsen et al. 2014. DSR II

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E-mail: Thomas.brown@plymouth.ac.uk
Website: www.IP25.co.uk

n = 300
ATMOSPHERE

- The Arctic is ringed by atmospheric monitoring stations (CO$_2$, CH$_4$, N$_2$O, O$_2$/N$_2$)
- Could be used with back-trajectory and inverse atmospheric modeling to obtain ocean-wide CO$_2$ source/sink and O$_2$ productivity.
- UK’s KJN station in Northern Norway “sees” the Barents and Kara Seas: APO at this site gives estimate of biological net production from here.

REMOTE SENSING

- Ice extent, productivity, gas exchange and hence CO$_2$ fluxes can be estimated from satellite:
- Barents sea CO$_2$ sink predicted to halve over the next 10 years: (Land and Shutler, *Biogeosciences*, 2013)
The variability of the Arctic carbon and biogeochemical cycles?

Ute Schuster, Uni Exeter

Changes, impacts and feedbacks of
- Riverine input?
- CO₂ uptake?
- Nutrient cycling?
- Warming?
- Ocean acidification?

Observations & models & observation / model comparisons

Hydrographic sections
IOCCP/UNESCO
Surface fCO₂ / sea-air fluxes
Ocean Acidification
Nitrogen Biogeochemistry & Greenhouse Gas Fluxes

CH$_4$ & N$_2$O production & consumption – and hence fluxes are sensitive to changing condition of OA, nutrients, temperature & O$_2$.

OA in Arctic waters likely to alter N stoichiometry and reduce N$_2$O production. Further effects of changing nutrients & increased temperature unknown.

Determine contemporary and future C & N remineralisation:

- N cycling, methanogenesis & methanotrophy
- source:sink fluxes of greenhouse gases
What are gas transfer rates in ice and broken ice? Some evidence that gas exchange is higher in leads than in open ocean. How will gas transfer rates change?

Direct flux measurements of CO$_2$, DMS, OVOCS & CH$_4$. Lagrangian/dual tracer experiment.

The role of Arctic waters as a source/sink for trace gases and how will this change. Evidence that DMS will decrease in Arctic waters (NERC OA).

Measurements of [DMS/DMSP], [halocarbons], [methyl amines] and [OVOCs] + production/consumption rates.

Role of the Arctic as a source/sink for atmospheric CO$_2$.

PML underway system already installed in JCR.

Phil Nightingale (pdn@pml.ac.uk), R. Beale, T. Bell, J. Dixon, F. Hopkins, V. Kitidis, M. Yang
Goal: to quantitatively assess the sensitivity of the Arctic ecosystem to sea-ice derived productivity versus open ocean productivity

Approach: construct a carbon (C) and nitrogen (N) isotope budget for the Arctic using historical and new observations alongside model simulations to test hypotheses

- Foodweb investigated in sea ice and open water
- Use international partners to compare C and N sources and food web structure to the western Arctic Ocean

Distinct δ\(^{15}\)N/δ\(^{13}\)C values of phytoplankton in sea ice versus open ocean environments

Eg δ\(^{15}\)N/δ\(^{18}\)O-nitrate, δ-Atlantic, δ-Pacific, δ-Rivers
Key outcomes of the project:

- Obtain a first order understanding of the processes (external nutrient supply, isotope kinetics) that regulate the isotope composition of the base of the food chain, which will provide a constraint on trophic level interactions.
- Understand importance of ice versus ice free productivity in supporting Arctic food webs.
- Constrain how the shift to ice free conditions will impact the food supply to upper trophic levels.

Addresses two key challenges in the NERC call:

- 1.1: Characterization of food webs and biogeochemical cycles in contrasting regions of ice cover.
- 2.1: Assess of the impact of changing inorganic and organic nutrient supply on ecosystem structure and function.
Expertise: **Zooplankton physiology, ecology, population dynamics; quantifying their role in biogeochemistry and food webs**

- Produced first global-scale understanding of mortality, growth and fecundity rates of zooplankton

- Corrected the equations and experimental protocols to determine mesozooplankton production

- Field experience (mortality, feeding, development rates), working experimentally on copepods, euphausiids, jellyfish etc, including in the Arctic and Antarctic

- Impacts of warming on physiology and life-history within species (e.g. phenotypic plasticity, Temperature-Size Rule, differential temp. dependence), including interaction of season-length and voltinism on adaptive responses
1. Response to Environment:
- Phenotypic plasticity
- Variation within population
- Individual and population response to change

2. Interlinking Physiology, Life-Cycle & Biogeochemistry:
- Rates in key species
- Upscaling to the community and fluxes [e.g. through trait-based mechanistic models]

3. Mind the Gaps:
- Food web structure
- Biodiversity
- Biogeochemical function
Microzooplankton

Observational components

- Graze up to 100% of PP
- Ingest small PP (*Arctic*)
- Food for zooplankton and larval fish
- Known to be important in the Arctic
- Functionally different taxa

**We need:**
- Abundance
- Biomass
- Sizes
- Functional groups

**We must examine:**
- Seasonal/regional *Trophic link*
- Blooms/local *Recyclers*

Experimental components

- Temperate parameters
- Arctic parameters

**We need ecophysiological parameters:**
- Ingestion, growth, sensitivity to drivers
- Recognise interactions

Q₁₀ may be wrong

Evaluate interactions between drivers
Microzooplankton

Montagnes
- >30 years examining microzooplankton
- Field ecology, functional ecology, taxonomy, ecophysiology
- Track record (Mar Prod)

Torkel Gissel Nielsen & Per Juel Hansen
Diane Stoecker & Bob Sanders
- Extensive Arctic experience
- Micro- Mesozooplankton experts
- Field experiments

Flynn/Mitra
- Most microzooplankton are mixotrophic...

Parameterising variable assimilation efficiency in predator–prey models
Andy Fenton, M. Spencer and D. J. S. Montagnes

\[
\frac{dV}{dt} = \mu V \left(1 - \frac{V}{K}\right) - \frac{V}{k_v + V} P
\]

\[
\frac{dP}{dt} = \frac{V}{k_v + V} P
\]
The world, and our understanding of it, is changing – we need to ensure models reflect reality

Flynn/Mitra Proposal

- Develop/validate mechanistic model descriptions vs data
- ... provide a lynchpin between empirical plankton studies and ecosystem models
- Need data on abundance & types of PFT and on allied vital rates (e.g., Montagnes)
- ... for multi-stressor systems learning how-not-to-do from earlier studies

- Develop scalable hierarchy for placement in ecosystem models of different levels of complexity (ERSEM, MEDUSA)

k.j.flynn@swansea.ac.uk
Quantified understanding of the structure and functioning of Arctic ecosystems.

- Standard organism approach
- Variable C:N:P + Fe, Si, O,
- Benthic pelagic coupling
- Explicit microbial loop
- Scalable ecosystem processes (FAMB)
- Coupled to regional and global hydrodynamics (e.g. NEMO, FVCOM)
- Climatically active gases (DMS, N”O)
- Top down vs bottom up control
- Function vs diversity
- Bespoke process models
- Linked into UKESM

Contact Icarus Allen jia@pml.ac.uk
Understand the sensitivity of Arctic ecosystem structure, functioning services to multiple stressors and the development of projections of the impacts of change.

- Large Scale projections
- Multiple stressors (e.g. climate pH, eutrophication, pollutants, fishing)
- Quantification of ecosystem Services (e.g. food provision, climate regulating services, bioremediation, foodwebs, etc...)
- Fisheries economics

Projections of fish habitat under climate change
1. Riverine DOC is increasing in temperate/boreal zone

2. $^{14}$C data show a shift from new (plant-derived) to old (soil-derived) DOC following ecosystem disturbance

3. Field and experimental data suggest active DOC removal and transformation along the freshwater-marine continuum
• JULES is a model of land surface, vegetation and soil processes
• Includes plant and soil carbon (including DOC) and nitrogen fluxes
• Used offline (global or regional domains) or as part of UKESM
• Current plans to add a river model to deliver C, N, P, Si to the ocean

Douglas Clark, dbcl@ceh.ac.uk
Glacier meltwater is important for Arctic Ocean ecosystems

Doug Mair$^{1,4}$, Andrew Sole$^2$, Tom Cowton$^3$, Brice Rea$^1$, Pete Nienow$^3$

Cumulative freshwater inflow from glaciers and ice caps to the Arctic Ocean has exceeded the net inflow of rivers since 1961 (Dyurgerov et al, 2010)

In shallow shelf /fiords phytoplankton blooms coincide with seasonal meltwater input from ice sheets & can exceed spring blooms (Juul-Pedersen et al, 2015)

1-University of Aberdeen
2-University of Sheffield
3-University of Edinburgh
4-University of Liverpool

MITgcm –biogeochemistry with sub grid scale glacial melt plume parameterisation

NO EXTRA NUTRIENTS

Sole, Cowton, et al. unpublished
• Current research:
  – contemporary processes and
  – long-term context (100s-1000 yrs) (Lea et al, 2014)

of tidewater glacier change

• Kangiata Nunaata Sermia:
  – Important now but also an analogue for future change elsewhere?
  – Collaboration with GINR
  – and others?

What processes need to be in models?
Calibration and validation of models
Our expertise: determining source of FW inputs into Polar seas and *reconstructing historic changes* in those inputs.
What is the real baseline?

- Quantify changes in inputs
- Determine input drivers (e.g. temperature)
- Marine inputs (Glacial / riverine)
- Reconstruct historic (centennial) changes

How will inputs change in the future?

Kamenos et al, Geology, 2012
Bristol Oceans Past and Present

Seawater chemistry (e.g. nutrient concentration)
Impact of climate on marine biology

Seawater temperature and salinity
Impact of climate on ocean circulation

Ecology and biodiversity
Impact of climate on populations and communities

Field work - Bristol led
- Collaborative e.g. N-ICE2015, GEOTRACES, CGS (BAS)

High precision trace metal concentrations – Pyle, Hendry et al., in prep

Radioisotopes – Hayes et al., 2015

Stable isotopes – Hendry et al., in prep

Lab work
ICP-MS facility
New AMS

Photo c/o P. Dodd

bristol.ac.uk
Palaeoceanography (seawater properties, ecology)
- e.g. Isolated glacial Arctic?
- Circum-Arctic connections during deglaciation?
- Late Holocene and the “Anthropocene”?

Hendry & Robinson, 2012; Hendry et al., in review

Margolin et al 2014
Using pore water and sediment chemistry to estimate benthic nutrient recycling from Arctic Ocean sediments

Christian März (Newcastle University, from May 2016 University of Leeds)

**Concept:**
- Organic matter from photic zone and/or from land settles to sea floor (**export flux**)
- Organic matter **remineralisation** in sediments releases nutrients to pore waters
- **Nutrients** (C, P, N, Si…) potentially **recycled** to bottom waters and to photic zone
- Degree of recycling **controlled** by (seasonal) export flux, organic matter quality, background sedimentation, water depth, water column stratification…

**Strategy:** Sampling of pore waters and surface sediments from Multicorers, Box Corers; sediment incubations; benthic chambers → Calculating/modelling fluxes

https://www.npolar.no
Importance/Track record/collaborations:

- Very few systematic studies, but potentially **important process** (März et al., 2015: Arctic Ocean-wide benthic silica fluxes roughly equal total riverine silica input)

- Participation in **sampling campaigns** in 2008, 2011, 2015 (Polarstern) → some existing data base

- **Network** of colleagues in Sweden, Norway, USA, Germany to collaborate and share ship time & data

- Interdisciplinary **TRANSSIZ** Expedition in 2015 (N of Svalbard) → similar aims as NERC Changing Arctic Ocean Programme → lots of potential synergies
1) Role of fish in ocean chemistry and biogeochemical cycles

Fish CaCO₃ Excretion: 3 to 45+ % of global marine CaCO₃ production

Fish Carbonates (High Mg calcites soluble at shallow depths) (Woosley et al (2012). J. Geophysical Sciences 117: C1048)

Rapid dissolution of fish carbonates – explain Alkalinity v. Depth profile in Pacific & Atlantic Oceans

Wilson et al. (2009) Science 323: 359-;
Perry et al. (2011) PNAS 108: 3865-

Potential roles in N & P cycles too
2) Impact of OA on sensory physiology, behaviour & fitness in Arctic fish

Elevated seawater CO₂

Blood acid-base regulation

(↑[HCO₃⁻] ↓[Cl⁻] )

Central brain
Neurotransmitter
dysfunction

↓ Fitness & ↓ Survival

Sensory-behaviours disrupted
(olfaction, hearing, vision, lateralisation, learning etc.)

Similar pattern across many tropical and temperate fish:

Munday et al. (2009) PNAS;

What about Polar fishes?

3) Responses of marine invertebrates to OA + environmental pollution
Phages are responsible for up to 40% of marine bacterial mortality, yet very little research to-date on phages in the Arctic.
Increased light, temperature, nutrients $\rightarrow$ increased bacterial production/abundance $\rightarrow$ increased viral abundance and activity

We need **baseline data on seasonal and spatial variation in Arctic viruses**: abundance, diversity, and potential activities (e.g., lytic vs. temperate, % infected cells)

Combination of approaches:
- **Observational**: metagenomics, microscopy, flow cytometry
- **Mesocosm/enrichment experiments**
- **Isolation**

Kuznetsov et al. 2010
Calanus hyperboreus
Consortium and skills

David Pond and Kim Last - Scottish Association for Marine Science
Zooplankton life cycles, demography, lipids and vertical migration

Dougie Speirs and Neil Banas - University of Strathclyde
Trait based and demographic models

Geraint Tarling - British Antarctic Survey
Foodwebs, depth stratified zooplankton sampling

Angus Atkinson - Plymouth Marine Laboratory
Zooplankton feeding, reproduction and phenology

Dan Mayor, Tom Anderson - National Oceanography Centre
Physiological ecology, Ecological theory

Danish and Norwegian collaborators - Food web expertise coupled with access to seasonal sampling opportunities
Questions

1) Controls on primary production and zooplankton
2) Implications for trophic/benthic coupling
3) Response to warming and sea-ice retreat:
   - adaptation vs invasion
   - pop structure, gene flow, hybridisation,…
   - advection, dispersal, life histories,…

Approach

Pop. Gen.
Community Ecology

Biogeo-chemical Cycles

GCMs & Populations
Community Composition & Function

Meta-omics
Genetic Diversity & Correlation Networks

Systems Biology

Autecology
GCM & Populations Optimality Principles

Physiology
Niche Modelling

Traits
Genomic Diversification & Correlation Networks

GCM & Populations

Functional Genomics

Benthos

HTL

Bloom
Pico

Snow
Ice algae
Sea ice
**FIELD**

Meta-omics  
Targeted sequencing  
Population Genetics  
PI Thomas Mock  
Co-I Cock van Oosterhout  
+ int partners: Paul Wassmann, Chris Bowler

**LAB**

Physiology  
Functional Genomics  
Co-I Graham Underwood  
+ int partners: Carlos Duarte

**MODEL**

Traits, Diversity  
Environmental selection  
Biogeochemistry  
Co-Is Tim Lenton, Jorn Bruggeman, Jim Clark  
Res. Co-I Stuart Daines

**TARA OCEANS POLAR CIRCLE**

2013 circumnavigation  
Year-round  
Fjord in Svalbard  
-omics datasets  
1) NERC cruises  
2) Polarstern cruises

+ copepod physiology?

GCM environment  
EVE IBM dispersal life histories
Biogeochemistry of the seasonal ice zone:
- Large seasonal changes (0.4 pH units, $\Omega_{ar} \sim >1$);
- Carbonate chemistry of sea ice;

Variation (spatial, seasonal, long-term) and impact
- Changing sea ice cover;
- Ocean acidification;
- Impact on ocean carbon sink, carbon export, TEP (transparent exopolymer particles) production;
- Interaction of biogeochemistry, biology, physics;
- Arctic (shelves, rivers) vs. Southern Ocean;

(e.g. Bakker et al., 2008, 2014; Bednaršek et al., 2012; Jones et al., 2010, 2015; Landschützer et al., 2015; Legge et al., 2015)
Carbon and ice in a changing Arctic Ocean
Dorothee Bakker, James France, Martin Johnson, Jan Kaiser et al.

- **Sea ice facility** (Coupled ocean - sea ice – atmosphere facility, ASIBIA) for studies of optics, biology, biogeochemistry, physics, sensor testing;
- **Integrated sea ice process studies** (repeat ship & Seaglider transects, ice stations);
- **Multi-year time series**;
- Carbonate chemistry (DIC, TA, $fCO_2$), CH$_4$, N$_2$O, TEP;
- Surface Ocean CO$_2$ Atlas, GLODAPv2;

Surface ocean $fCO_2$
1981-2014

0°W during ice melt
Arctic biogeochemistry: Sensitivity to change

Carol Robinson, Elena Garcia-Martin, Erik Buitenhuis, Andrew Manning, Jan Kaiser, Colin Murrell, Jenny Pratscher et al.

- **C & N cycling through marine foodweb – different ice conditions**
  - Community, bacterial, zooplankton respiration \([O_2, \text{INT}_R]\)
  - Gross production, net community production \([O_2/\text{Ar}, \Delta^{17}\text{O} (O_2), \text{gliders}]\)
  - N assimilation, nitrification, N\(_2\) fixation, denitrification \([\partial^{15}\text{N} \partial^{18}\text{O} (\text{NO}_3^-)]\)
  - Microbial community [metagenomics, functional gene probing]

- **Changing inorganic / organic nutrient supply + increasing T**
  - Nutrient stoichiometry effect on zooplankton production
  - DOM concentration & composition effect on respiration / C storage

- **Seasonality & basin scale**
  - Modelling, isotopes, atmospheric O\(_2/N_2\), gliders, remote sensing

*Garcia-Martin et al., Nobili et al., 2013; Jiao et al., 2014, 2015; Tilstone et al., 2015, Kaiser et al., 2005, 2011; Rafter et al., 2013*
Experienced glider and AUV operators in polar regions (Kaufman et al. 2014; Thomson et al. 2014; Smith et al. 2014) and for year-round monitoring (Thomson et al.; Damerell et al.)

Well placed to undertake continuous long-term observations in the Greenland Sea or polynyas (combined with seal tags)

Deployment from research ships to support interdisciplinary process studies, from ships of opportunity, or the ice edge

In-house technical support, piloting, processing methodologies, and data analysis experience, e.g.

- Net Community Production (NCP; Biddle et al. 2015; Queste et al. 2015)
- Wind and tidal driven mixing rates (Creed et al. 2015)
- Zooplankton/krill biomass (Guihen et al. 2014)
- Acoustic marine mammal monitoring

Contacts: Karen Heywood, Rob Hall, Jan Kaiser
Biogeochemical and Ecosystem Modelling for Arctic Science
Parv Suntharalingam, Corinne Le Quéré, Erik Buitenhuis, Oliver Andrews

Modelling biogeochemical cycles:

şi Expertise and modelling capability to address the impacts of the changing Arctic environment on marine ecosystems and ocean biogeochemistry
şi NEMO-PlankTOM hierarchy of ocean models include major biogeochemical cycles (C, N, P, O₂, Fe, Si)
şi Well suited to study the implications of Arctic changes for trace gases (CO₂, N₂O, DMS)
şi Recent investigations address:
  - Impacts of anthropogenic nutrient deposition on ocean biogeochemistry
  - Detection and Attribution of climate change on oceanic oxygen
  - Top-down constraints on ocean carbon fluxes using atmospheric inverse analyses of CO₂ and O₂/N₂

Modelling marine ecosystems:

✧ NEMO-PlankTOM represents multiple Plankton Functional Types: bacteria, six phytoplankton, five zooplankton, and their trophic interactions

✧ NEMO-PlankTOM well suited to study multiple stressors on marine ecosystems and implications of a changing environment

✧ Recent investigations address:
  - Key role of zooplankton dynamics in controlling high-latitude primary and export production
  - Key role of zooplankton dynamics in projections of biogeochemical changes to 2100
  - Importance of zooplankton calcifiers (e.g. pteropods) for the alkalinity cycle

Le Quéré et al. 2015, Buitenhuis et al. 2013b, Moriarty et al. 2013
Melt pond evolution: microbiological and biogeochemical feedbacks

Significant issue for current sea ice modelling – melt ponds can account for up to 40% of ice ablation

Research required to capture PAR and albedo change as the result of evolution of microbial consortia, which potentially darken the water column and ice floor significantly.

Nutrient, brine drainage and under-ice productivity impacted.

Predictive models need to include process information.
Bristol, Sheffield and Southampton have expertise in polar microbiology and biology, biogeochemistry, and multi-scale remote sensing and modelling of ice and marine environments.

- Jemma Wadham, Alex Anesio, Sandra Arndt, Jon Bamber, Fanny Monteiro, Martyn Tranter, Marion Yallop (Bristol)
- Andy Hodson, Grant Bigg, Edward Hanna, Andy Sole (Sheffield)
- Duncan Purdie (NOC, Southampton)
- Strong European and US collaboration

Source: Arrigo, Science, 2012
Linking rivers to deep ocean, atmosphere to seafloor

NOC-Liverpool Shelf sea physics
From physics to phytoplankton

Matthew Palmer (matthew.palmer@noc.ac.uk)
Jo Hopkins (jeh200@noc.ac.uk)
The Arctic Ocean carbon sink

- Arctic Ocean responsible for ~10% of global oceanic carbon uptake (3% of global ocean area)
- Arctic Ocean carbon sink overwhelmingly dominated by soft tissue pump in Baffin Bay
- Assess key factors in future evolution of the Arctic Ocean carbon sink by unravelling major present signal
- Establish annual cycle of physical and biogeochemical terms in regional carbon sink
Biogenic SOA tracers in summertime Arctic aerosol

Lucy Carpenter, Univ of York

FT-ICR-MS spectra of aerosol extracts

Spring

Summer

C$_8$H$_{11}$O$_6^-$  C$_8$H$_{11}$O$_5^-$  C$_9$H$_{10}$O$_3$

RVL 2-5  RVL 8-11  BLANK  JR288 5-7  JR288 20-23

4 day back trajectories

Marine SOA precursors – what are the sources?

Surface isoprene and pigments

Monoterpene sea-air fluxes

Biological data from K. Reifel/R. Airs
Iodine associated with Arctic new particle formation

Size-resolved number concentrations as a function of diameter, total number concentrations and iodine ion concentrations ($m/z$ 127) Allan et al., ACP, 2015

A mechanism for biologically induced iodine emissions from sea ice Saiz-Lopez, Boxe and Carpenter, ACP, 2015

What and how well spread is the source of Arctic iodine?
Key science questions

Which primary producers provide energy to higher food web organisms across seasons?

How do Arctic and Boreal foodwebs differ in PP sources?

How are nutrients moved biologically within, into and out of Arctic ecosystems?

Clive Trueman: Univ. Southampton
Nick Polunin: Univ. Newcastle

Kortsch et al., 2015
Approach / skills

Tracking PP source within food webs:
• CS-IRMS analyses of amino and fatty acids
• Develop biogeochemical fingerprints from field primary production samples
• Use existing high TL species samples to quantify proportional sources through food webs
• Feed back to food web models

Linking to ecosystem models:
• Model isoscapes from MEDUSA – spatial variation currently with 2 PP types
• Sample PP across gradients to validate MEDUSA predictions
• Analyse archive migratory high TL species to identify biological import and export of nutrients

Archive samples: >1500 samples from benthic + pelagic systems: mostly TL >2.5

trueman@noc.soton.ac.uk                      nick.polunin@newcastle.ac.uk
Dr. Sabine Matallana-Surget

MARINE BIOLOGIST – Microbiology – Molecular Biology

UV-C  UV-B  UV-A  PAR  IR

BACTERIA  STRESSES  CELL RESPONSE
SUNLIGHT – UV RADIATION  PROTEOMICS
The Arctic ozone hole, similar in size to the Antarctic ozone hole affects the northern parts of UK. The resulting increase in UVB radiation significantly impacts sensitive marine microorganisms.
Benthic carbon accumulation & sequestration in a changing Arctic

1. Strong interdisciplinary team
2. Proven novel apparatus
3. Track record

BAS  Barnes DKA, Sands CJ, Linse K, Smith J, Hogan K, Hodgson D
SAMS  Narayanaswamy B, Cottier F
PML  Ingels J, Findlay H, Queiros A
NOC  Hogg O,
Exeter  Graham A,
Liverpool  Jeffries R
Strathclyde  McKee D,
Senckenberg Downey R
1. Quantify benthic carbon standing stock & production
2. Estimate accumulation, per unit time, per unit area
3. Assess accumulation conversion to sequestration
4. Role in total flux and Arctic ecosystem response

Benthos ~5% Arctic C cycling?
> accumulation & >> sequestration?
a major sink, -ve feedback to climate change? is it changing?

Is Arctic benthic C predictable from Antarctic patterns?
• Arctic through-flow important for global N balance

• Arctic N cycling and water mass mixing are key

• subject to changes with sea ice loss, terrestrial inputs, water mass changes ..... 

• How Arctic nutrient balance will change?

• Combined N & O isotopes of nitrate: delineate water Mass sources, N cycling processes

• GEOTRACES, TRANSARC II, ELLET LINE

Yamamoto-Kawai, et al., 2006
**Simon Tett:** Climate model Projections, Future of Arctic upper ocean mixing processes

**Sian Henley:** C, N stable isotope, N cycling, DON

**Alex Thomas:** P is various phases (particulate, colloids, DOP)

**Discussion:** SAMS, Liverpool....

**Collaborators:** Arctic GEOTRACES, AWI (Germany), Canada, USA

Wassmann, 2012
The importance of changes in coupling dynamics

Mathis et al. 2013

Simmonds and Keay (2009)

Jonny Day
APPOSITE: How predictable are changes in Arctic climate?

Day et al. (2014)

De=Decadal
Se=Seasonal
An=Annual

Jonny Day
Mechanistic understanding of marine heterotrophs and climate-active trace gas cycles

Yin Chen, University of Warwick
Y.CHEN.25@warwick.ac.uk

Phytoplankton

Zooplankton

Heterotrophic bacteria

Labile organic substrate

Methylamines
N-osmolytes
Polyamines etc

NH$_4^+$ regeneration

CO$_2$

Ice melting

Climate active trace gases

Direct: Dimethylamine (DMA)
Indirect: Dimethylsulfide (DMS)

Trace metals
Mechanistic understanding of marine heterotrophs and climate-active trace gas cycles


Yin Chen, University of Warwick
Y.CHEN.25@warwick.ac.uk

Scientific questions

- Assimilation /dissimilation activities
- Sources/ Standing concentrations
- **Mechanisms of metabolism**
- Seasonality/ environmental regulation
- Contribution to DON/DOC pool and to C/N/energy demand of marine bacteria

Approaches

- Microbiology and physiology
- Molecular microbiology, genetics
- Biochemistry, enzymology
- Microbial ecology, amplicon sequencing
- Stable-isotope/radioisotope labelling
- Modelling, prediction in response to environmental regulation (e.g. trace metals availability)
Geoffrey Abbott
Why dissolved organic matter in the Arctic?

- High river discharge and Yedoma permafrost thaw
- Connect sea with world’s largest peat carbon stocks
- High levels of
  - DOM (~2-3-fold enhanced)
  - Coloured DOM
  - Lignin phenols (~10-fold en.)
  - Highest DOM levels of any ocean basin
- DOM & POM discharge expected to increase further
- \(\Rightarrow\) Fate of terrestrial DOM & POM?

Figure from Dittmar, T. and Kattner, G., 2003. The biogeochemistry of the river and shelf ecosystem of the Arctic Ocean: A review. Marine Chemistry, 83(3-4): 103-120.
Iron trap at redox interfaces depicting anoxic pore water, oxidation of iron with surficial oxic waters, and coprecipitation of terrestrial DOM with Fe(III). C\textsubscript{org} resequistered by reactive iron on Eurasian Arctic shelf (Salvado et al 2015 Geophys. Res. Letters) Selective retention of phenolic acids in conjunction with iron precipitation.

Figure from Riedel et al (2013) Iron traps terrestrially derived dissolved organic matter at redox interfaces

PNAS 110, 10101-10105

**What do we do?**

Lignin phenols from vascular plants eg Mason, Filley & Abbott (2013) Organic Geochemistry

Peat contains sphagnum acid


Sphagnum acid derived phenols detected by THM-GC-MS

Time of flight secondary ion mass spectrometry and XPS

DOM (Williams, Dungait, Bol & Abbott, 2015)

**Collaborators:** Maerz (Fe); Professor Elena Lapshina Yugra State University Siberia

**These are the questions we wish to address:**

- What is effect of ice melting on DOM/POM and its availability? Are these co-precipitation reactions inhibited or are they promoted? If DOM/POM is being mineralized to carbon dioxide or methane then this may be another feedback process? Lab and field studies (transect and sediment traps). **Use our methods to characterize and quantify the molecular composition of DOM/POM.**
Improved understanding of biogeochemical cycles of hydrocarbons and the role of the oceans.

Dr Neil Harris  Dr Alex Archibald
(ata27@cam.ac.uk)

- Development of complex chemistry models (100s-1,000s ODEs).
- Emulation of complex models.
- Sensitivity analysis.
- Simplification.

Lea-Smith et al., PNAS, 2015
New GC instrument developed for autonomous sampling of isoprene in air.
Currently investigating using commercial shipping companies in South-East Asia.
Earth Observation Research into the Carbon Cycle

- PML research on the global carbon cycle from EO of relevance to Arctic Challenges 1 and 2:
  - Size fractionated phytoplankton (e.g. Brewin et al., 2015; 2014a,b)
  - Primary and new production (e.g. Tilstone et al., 2015 a,b)
  - Ocean acidification parameters (e.g. Land et al., 2015)
  - Ocean carbon pools (e.g. Martinez-Vicente et al., 2013)
  - Phytoplankton phenology (e.g. Racault et al., 2015,2014)

- Arctic is under-sampled in these studies

- Analysis of Bio-Argo data: carbon export by small particles in the Norwegian Sea

Dall’Olmo and Mork, 2014
NERC EO Data Acquisition & Analysis Service

- NEODAAS is a NERC service run by PML and University of Dundee
  - Can provide time series data for the Arctic
  - Unique or bespoke data products e.g. ocean fronts, regional algorithms
- Near-real time processing where timeliness of delivery is key
  - e.g. to guide research aircraft and cruise campaigns or sea-glider deployment to
    maximise science value of these expensive resources

- During Arctic fieldwork should be two ESA ocean colour sensors in operation with 300m resolution
- Arctic proposals should include formal requests (and access costs) for NERC Services and Facilities like NEODAAS
- Steve Groom, PML: sbg@pml.ac.uk
Kieran O’Driscoll, Queen’s University Belfast

- Competencies: Hydrodynamic, cycling and fate of persistent organic pollutants (POPs) modelling; US Naval Oceanographic Office (8 yr); University Hamburg (4 yr)

- Model processes include: equilibrium partitioning between dissolution and sorption to organic matter; sinking to sediment, deposition, sedimentation, resuspension; advection and mixing; degradation¹,²

- Model validated for the North Sea

- Present work: POP modelling in Black and Marmara Seas and Taiwanese waters; climate effects on freshwater deposition due to storms in Tropical Pacific (US/Ireland NSF, partners UW-APL, NUI Galway)

- Predicted 21st century scenario: γ-HCH burden increases in sediment; PCB 153 burden to atmosphere increases

• Capabilities: **alternative and complementary models** readily adaptable for simulation of POP processes at high latitudes

• **Challenge:** further develop model to simulate POP exchange processes at lower trophic levels (LTLs), including **bioaccumulation** and **biomagnification**, accommodation of ice melting, etc, and emerging problems (plastics)

• **International collaborators** (study regions): Shirshov Institute of Oceanology, Russia (Arctic Ocean and approaches); Applied Physics Laboratory, University of Washington (North Pacific and Arctic approaches); National University of Ireland, Galway (North Atlantic and Arctic approaches); Institute of Environmental Assessment and Water Research, Barcelona (POP exchange processes theoretical framework at LTLs); Istanbul Technical University, Turkey (Black and Marmara Sea); Tainan Hydraulics Laboratory, National Cheng Kung University, Taiwan (Northwest Pacific); Griffith University, Australia (Southern, Pacific and Indian Oceans)

• Queen’s collaborations (cross-disciplinary): POP modelling and ecosystem processes (School of Biological Sciences, QUB)

• **Contact details:** Dr. Kieran O’Driscoll, School of Planning, Architecture & Civil Engineering, Queen’s University Belfast; email: kieran.odriscoll@qub.ac.uk; tel/skype: 028 9097 4204; mob: 0745 012 0925; url: http://pure.qub.ac.uk/portal/en/persons/kieran-odriscoll%2876915c8a-ef45-4ddb-8979-5d416fe8aedb%29.html
Impact of ice sheet runoff on fjord and coastal biogeochemistry

- Monthly primary production from the mouth of Godthabsfjord, south west Greenland (Juul-Pedersen et al., 2015)
- Note the unusual double bloom pattern: the first classic spring bloom, and the second thought to be related to ice sheet runoff

- Model experiments conducted using MITgcm [http://mitgcm.org/](http://mitgcm.org/), a sub grid scale plume parameterisation by Tom Cowton (IcePlume - see Cowton et al., 2015, JGR: Oceans) and the biogeochemistry modules of MITgcm
- The domain represents a ‘typical’ large glaciated Greenlandic fjord. The fjord is 5 km wide, approximately 80 km long and 600 m deep
- Freshwater is injected at the bed of the fjord between days 180 and 270 with a mean discharge as shown in the legend
- The model is able to qualitatively reproduce the double bloom pattern, with the amplitude of the second bloom controlled by the magnitude of runoff
A relationship between net community productivity and ice sheet runoff emerges from the experiments shown on the previous slide.

A large glacier-fjord system such as Kangerdlugssuaq in east Greenland likely currently falls somewhere towards the bottom of the most sensitive part of the curve.

Other fjords will vary in terms of depth, ice sheet runoff rate and stratification and so will fall at different points along a curve similar to the one shown.
Wave Gliders as observational platforms:
1. Met data
2. High-accuracy sea level and wave measurements
3. Echo-sounding and ADCP surveying
4. Passive acoustic monitoring (sea mammals)
1. Latitudinal gradient of time series sites
   we are on ICES phyto- and zooplankton working groups:
   [http://wgze.net/zooplankton-status-report](http://wgze.net/zooplankton-status-report)
   [http://www.ices.dk/community/groups/Pages/WGIMT.aspx](http://www.ices.dk/community/groups/Pages/WGIMT.aspx)

2. Access and use of these time series data
   e.g. to understand role of phenology shifts and trophic mismatch
   (Atkinson et al. Prog Oceanog 2015, 137:498-512)
3. Use the new FlowCAM and our image library to classify and measure particles for biomass spectra or feeding experiments.

4. Expertise in molecular AND microscope methods for plankton identification, including *Calanus* species.

(Lindeque et al. PloS One 2013 8 no 11 e81327)
Ceri Lewis

Research focus: the physiological and life history responses of marine invertebrates to impacts of ocean acidification and environmental pollution.

Two Arctic Ice-Base Expeditions in 2010 and 2011 with Helen Findlay PML: Catlin Arctic Survey – Investigating the rate and biological effects of ocean acidification in the high Arctic.

NERC Fellowship: Broadcast spawning into a changing marine environment.

EU FP7 Clean Sea – Biological effects of marine Microplastics.

NERC UK Ocean Acidification Research Programme.

NERC Grant: Biological Effect of marine microplastics.
Dr Crispin Halsall
Reader in Environmental Organic Chemistry

“Persistent chemical stressors in the Arctic marine system”

Fate & process studies

c.halsall@lancaster.ac.uk
**Figure 1.** ΣC₈-C₉ perfluorocarboxylate concentrations in Arctic snow, sea-ice and seawater for seasonal, multi-year and first-year sea-ice systems in the European and Canadian Arctic.
Why are greatly elevated concentrations of perfluoro-contaminants observed in sea ice?
Operational remit
We are a NERC-funded state-of-the-art stable isotope mass spectrometry facility providing analytical & collaborative research opportunities of the highest quality to the UK Life Sciences community

What analyses can we do?
Primarily, Stable Isotope Analyses (SIA) of organic tissues:
\( \delta^{13}C, \delta^{15}N, \delta^{34}S, \delta^2H \) and \( \delta^{18}O \) of organic materials
a nondestructive/non-invasive method of elucidating diet

Project areas
- Food webs/trophic ecology:
  Stable isotopes give broad indications of diet.
  Pelagic, benthic and sympagic primary production have distinct \( \delta^{13}C \).
  Archived tissue samples provide evidence of how the Arctic food web is changing

- Animal migration:
  SIA along incrementally grown inert tissues (e.g. baleen, teeth, hair),
  utilising known latitudinal changes in baseline \( \delta^{13}C \) and \( \delta^2H \)

- Biogeochemical cycles:
  \( \delta^{13}C \) and \( \delta^{18}O \) of carbonates
  \( \delta^{13}C \) of dissolved inorganic carbon (DIC)
  \( \delta^{18}O \) and \( \delta^2H \) of waters

Predators of nekton, invertebrates and carrion
Predators of suspension feeders and omnivores
Omnivores
Suspension feeders
POM
Scotia sea foodweb, Stowasser et al. 2012
Kerguelen elephant seal whisker
Gallon/Newton unpubl.
Key LSMSF-EK features

- Scientific rigour on quality control
- High quality outputs & deliverables
- Student/postdoctoral training
- Method development to suit research
- Pilot projects to facilitate new research areas
- Extensive mass spectrometry expertise
- Advice and collaboration
- Access to our sister labs in Bristol and Lancaster
- Access to the earth sciences SIA facilities at SUERC

How to apply

We are accessible to UK Life Scientists & NERC funded researchers working within the remit of the NERC Science strategy
Contact Dr. Jason Newton
jason.newton@glasgow.ac.uk
(application submission in September and April each year)

Further information:
http://www.gla.ac.uk/research/az/suerc/nercfacilities/lifesciencemassspectrometryfacility/
Dr Liz Bagshaw, Cardiff University
School of Earth and Ocean Sciences

• Interests: sediment-bound nutrient export from ice sheets
• Expertise:
  • In situ biogeochemical monitoring
  • Novel methods for sediment tracking
  • Laboratory simulation of low temperature biogeochemical processes
Dr Roo Perkins, Cardiff University
School of Earth and Ocean Sciences

• Interests: physiology of changing phytoplankton communities

• Expertise:
  • Algal productivity
  • Novel methods for sediment tracking
  • Laboratory simulation of low temperature biogeochemical processes
Key Science Questions

- What is the biomass of food that Arctic seabirds consume, and how is this distributed through time and space and across habitats and prey taxa?

- What is the role the Arctic seabirds play in transport of nutrients from sea to land during the breeding season, and among Boreal and Arctic zones during migration?

- How will changing Arctic environments affect the role of seabirds in Arctic food-webs in the future?

- What implications will these changes have for the ecosystem services seabirds provide (hunting, ecotourism, sea-land nutrient transport)?

Brünnich’s guillemot in Arctic Norway equipped with miniature GPS logger
Approach/skills

- Tracking movements of seabirds from key breeding localities situated in contrasting physical environments
- Simultaneous ship-based surveys within foraging ranges of these colonies (collecting data on bird densities, physical oceanography and prey fields)
- Conventional and molecular assessments of seabird diets (e.g. stable isotopes in blood plasma and feathers, DNA in faeces)
- Spatial bioenergetics modelling of food consumption (Ratcliffe et al. 2015. *Diversity and Distributions* **21**: 1339-1348)
- Incorporation of estimates into wider food-web models
- In-kind support from Arctic member states via my links with CAFF C-BIRD group

Norm Ratcliffe: notc@bas.ac.uk
Nutrients in a changing Arctic Ocean

• Research interests
  • Effect of warming and sea ice losses on primary productivity and nutrient cycling
  • Dissolved organic matter and nutrient recycling
  • Ice-ocean-atmosphere interactions

• Expertise
  • Nitrogen and carbon stable isotope biogeochemistry
  • Polar marine nutrient budgets and cycling
  • Sea ice biogeochemical processes
  • Climate-ice-ocean-ecosystem interactions

Sian Henley  NERC Independent Research Fellow
Research Focus – Microbial Ecology
(Graham Underwood, Terry McGenity, Alex Dumbrell)

General expertise / interests
- C (DOM, BVOCs, hydrocarbons) and N cycling
- NGS meta-omics and bioinformatics
- Ice diatom production and distribution
- Food web (microbial loop), $^{13}$C (DNA) SIP, isotope ratios

Key capacities
- High-throughput automated (robotic) NGS prep and bioinformatics pipelines
- Temperature / light-controlled incubation facilities for mesocosms, microbial culture
- Automated physicochemical analysis suites
Arctic Expertise – (Field) Track Record
(Graham Underwood, Terry McGenity, Alex Dumbrell)

**Underwood** (DN Thomas, JE Hallsworth)
- Role of sea ice EPS and DOM production.
  NERC NE/NE/D00681/1 & NE/E016251/1 (£400k)

**Underwood, McGenity, Dumbrell** (NJ Anderson)
- The key role of DOM in regulating microbial diversity, community structure and organic carbon cycling in arctic lakes.
  NERC NE/J022063/1 (£395k)

**Dumbrell** (G. Woodward T. Bell, M. Trimmer et al.)
- Impacts of global warming in sentinel systems: from genes to ecosystems [arctic freshwater microbial ecology].
  NERC NE/M02086X/1 (£762K)
Consequences of changing sea-ice cover for Arctic benthic ecosystems (NERC 2013-16)

Approach: biomarker studies (e.g. IP 25, lipids)
Benthic fluxes & isotope tracing;
Benthic Observatory